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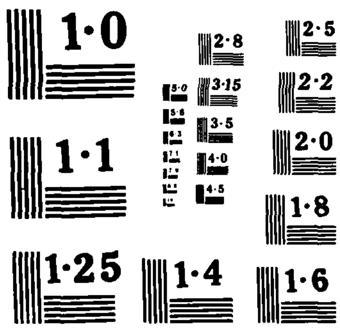

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AN EXPLORATORY STUDY OF THE EFFECT OF SCREEN SIZE AND RESOLUTION ON THE LEGIBILITY OF GRAPHICS IN AUTOMATED JOB PERFORMANCE AIDS

MAY 1985

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO FLORIDA 32813

AIR FORCE HUMAN RESOURCES LABORATORY
BROOKS AIR FORCE BASE TEXAS 78235

COOPERATIVE STUDY SERIES

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The electronic delivery of technical information in computer-based job performance aids (JPAs) for maintenance will rely heavily on graphic displays of schematics, printed circuit (PC) boards, illustrated parts breakdowns (IPBs), and locator diagrams. Optimal levels of critical visual display parameters such as screen size and resolution must be identified to maximize the efficiency and effectiveness of task performance and to determine device design requirements. The purpose of this experiment was to determine how locator task performance varied as a function of changes in display screen size and resolution when information needed to perform a task is presented in a graphic format. Graphic displays of PC boards were presented on a cathode ray tube (CRT) under varying conditions of screen size (5"x5", 9"x9", and 12"x12") and resolution (35, 70, 140, 280 dots per inch). Students were asked to locate test points on an actual PC board, based on test points identified by a flashing arrow on a graphic display of the PC board.
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The results demonstrated that screen size affected response accuracy only when the graphic display contained a large number of highly similar, densely packed test points (i.e., there was low descriminability among the test points). In this case, the largest screen size produced the highest accuracy rates. Screen size did not affect response accuracy when the test points on the graphic display were of many different shapes and sizes (i.e., there was high discriminability among the test points). The findings also revealed that resolution had no affect on response accuracy. In terms of response time, the data suggested that screen size did not affect the time needed to perform the task. Finally, although response time differences between resolution levels reached statistical significance in some instances, this finding has little practical significance when examined in the context of overall maintenance task performance.

PREFACE

This is the sixth in a series of cooperative research efforts that began in 1978 between the Naval Training Equipment Center and the Air Force Human Resources Laboratory. The present study was carried out at Lowry Air Force Base, Colorado, during the summer of 1983. Unlike previous research performed under the Cooperative Study Series which focused on flight training, the present study examines issues related to the use of automated job performance aids (JPAs) for maintenance.

Both the Naval Training Equipment Center and the Air Force Human Resources Laboratory are engaged in research aimed at developing automated JPAs for maintenance. Although the two research programs differ in many respects, there are, nonetheless, several shared research issues which must be resolved before the systems can be fielded. The issues addressed in this study concern the presentation of technical information via electronic delivery media. The study examines how changes in display screen size and level of resolution impact maintenance task performance when technical information is presented on a CRT.

Both commands shared in performing this research. The Naval Training Equipment Center developed the research design, prepared the experimental materials in a hardcopy format, analyzed the data, and prepared the technical report. The Air Force Human Resources Laboratory provided the computer hardware, developed the software, provided the testbed equipment, converted the hardcopy experimental materials to an electronic format, coordinated and carried out the data collection, provided financial support, and reviewed the technical report.

Several individuals made significant contributions to this research. Mr. Donald Thomas of the Air Force Human Resources Laboratory (Wright Patterson Air Force Base), 1st Lt Bradley J. Poulliot of the Air Force Human Resources Laboratory (Lowry Air Force Base), and Mr. Erich Pearson of the Denver Research Institute provided the technical expertise required to accomplish the research.

Thirty-six enlisted Air Force students from the 3453rd Student Squadron at the Lowry Technical Training Center served as subjects in this experiment. They are to be commended for their participation and cooperation during the study. The students were made available through the efforts of SSgt David Mann, the Student Training Advisor, and SSgt Kevin Robinson, both of the 3405th Student Squadron at Lowry Technical Training Center. Their assistance is greatly appreciated.

Also, a special thank-you goes to those individuals who reviewed early drafts of this report and provided valuable comments. They include Dr. Eduardo Salas, Dr. James Driskell, Dr. Richard Reynolds, Dr. Arthur Blaiwes, Dr. Dee Andrews, Dr. Charles Beagles, and Mr. Dennis Weller, of the Naval Training Equipment Center's Human Factors Division. Finally, my sincere appreciation goes to Ms. Wanda Allard for her many hours of work involved in the preparation and production of this report.

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SECTION I

INTRODUCTION

BACKGROUND

The Naval Training Equipment Center (NAVTRAEQUIPCEN) and the Air Force Human Resources Laboratory (AFHRL) are developing automated job performance aids (JPAs) for maintenance. The purpose of the NAVTRAEQUIPCEN program is to develop a prototype Personal Electronic Aid for Maintenance (PEAM) which is a small, lightweight, portable JPA that can be transported by maintenance personnel to the job site. The system is intended to be used for the presentation of technical information in support of organizational (O) level maintenance of Navy weapon systems. The AFHRL program (Automated Technical Data Requirements Design Study) is directed toward the development of a prototype technical data presentation system for intermediate (I) level maintenance of Air Force weapon systems with subsequent follow-on applications for O level maintenance.

The two programs differ in terms of the type and scope of the technical data to be presented, the environmental conditions under which the systems must operate, and the constraints (e.g., size, memory, durability) placed on the systems. The programs overlap, however, in that both involve the presentation of technical information via an electronic display medium.

The use of electronic delivery media for job performance aiding requires a careful consideration of the design variables associated with the presentation of technical information. Poor design, inaccurately specified visual display parameters, and/or omission of critical design features can hinder legibility and may result in a JPA device which is not used or which may prove to be ineffective in providing troubleshooting assistance.

Many design features can potentially impact the legibility of technical information presented on electronic delivery media. Consequently, it becomes critical to derive research-based standards to determine the delivery media requirements, and ultimately JPA device design. Past research has focused primarily on character attributes (alphanumerics) and has provided design guidance on variables such as optimum symbol size, character fonts, luminance levels, contrast ratios, etc. (See Appendix A for a summary of this past research and Meister (1984) for a complete review). However, there has been a lack of research on the legibility of graphic displays, particularly line drawings, presented via electronic delivery media (Swezey and Davis, 1983). Since automated technical data will make extensive use of graphics (e.g., PC boards, schematics, locator diagrams, IPBs), the legibility of the stimulus materials must be optimized in order to promote efficient and effective maintenance task performance.

PRESENT STUDY

The present study, the first in a more protracted research program on the legibility of graphics in JPAs, was designed to assess the effect of alternate display (CRT) screen sizes and resolution levels on user ability to identify and locate PC board test points. Screen size was examined because of its direct impact on device portability, a primary design consideration. Smaller displays not only promote portability, but are also less expensive than larger ones. However, the impact of small screen graphics on legibility is unclear. The presentation of high density (complex) graphics on small screen sizes tends to produce a "cluttered" display which may interfere with the ability to accurately perceive and discriminate between components of the graphic (Swezey and Davis, 1983). Therefore, it is important to determine the effect of screen size on legibility of graphics.

The second variable examined was display resolution. Despite Gould's (1968) recommendation of 50 scan lines (i.e., picture elements or "pixels") per inch for graphics, high resolution is often assumed to be warranted because of the greater display clarity and the intuitive belief that higher resolution (automatically) improves legibility. Because of the lower costs associated with low resolution graphics production and the impact of resolution on display monitor requirements, it is important to determine if low resolution graphics impact legibility. It is also important to determine if higher resolution can provide enough clarity to "compensate" for small screen clutter when complex graphics are displayed.

The present study examined three CRT screen sizes (5"x5", 9"x9", and 12"x12") and four levels of resolution (35, 70, 140, and 280 dots (i.e., pixels) per inch) and assessed the impact of changes in these variables on locator task performance. The three screen sizes and the four resolution levels were selected because of their representativeness of the range of display screens commercially available. The task involved locating test points (i.e., components and solder connections) on two actual PC boards (one component side and one pin side) based on test points identified in a graphic display. It was hypothesized that performance would not be differentially affected by screen size or by resolution level for either the component side or pin side PC board displays.

SECTION II

METHOD

SAMPLE

Thirty-six Air Force maintenance training pipeline students (35 male and 1 female) served as participants in the study. All students were enrolled in the Precision Measurement Electronics Speciality course (Number 3ADR324XD) at the Lowry Technical Training Center, Lowry Air Force Base, CO. The students ranged in age from 18 to 26 years with a mean age of 20.6 years. Length of time in Air Force service for the students ranged from 7 weeks to 10 months with a mean length of time in service of 4.1 months. Seventeen of the students wore glasses (or contact lenses), 19 did not. Visual acuity was not assessed. All students were first term enlistees attending their first Air Force technical school. Of the 36 students, three indicated that they had received some high school electronics training and one indicated that he attended a five-month communications electronics course at a private technical school. For the remaining students, the Precision Measurement Electronics Speciality course constituted their only electronics training.

APPARATUS

The Megatek 7210 high resolution vector graphics system driven by the Digital Equipment Corporation (DEC) PDP 11/34 mini-computer (Megatek/PDP) was the system used for presentation of the stimulus materials to the students. The Megatek/PDP graphics system was a configuration established specifically for this study and consisted of the following: (1) a Megatek vector-type graphics display, (2) a Megatek graphics processor and associated peripherals, (3) a Digi-Pad 5 graphics digitizer, (4) a PDP 11/34 processor and associated peripherals, and (5) a DEC VT100 terminal for keyboard input.

The Control Data Corporation (CDC) CYBER 73-16 mainframe computer was also used in support of this study. In order to take advantage of the graphics development tools available on the CYBER 73-16 system, an emulation program written in FORTRAN on the PDP 11/34 was developed to interface the Megatek/PDP graphics system with the CYBER 73-16. The emulation program was designed to make the Megatek/PDP graphics system function as a Chromatics CG Series graphics terminal for which the CYBER 73-16 has support facilities. The emulation program was also designed to simulate the three display screen sizes and the four levels of resolution.

Two actual PC boards (the transmitter and the synthesizer boards) from the AN/ARC-164 UHF Radio were also used in the study. The sizes of the actual PC boards and the graphic PC boards are presented in Table 1.

TABLE 1 - PC BOARD DIMENSIONS IN INCHES*

	Transmitter Board	Synthesizer Board
Actual Board	4.94x4.69	4.50x4.00
5x5" Graphic	4.75x4.38	4.31x3.75
9x9" Graphic	8.63x8.00	7.81x6.75
12x12" Graphic	11.63x10.75	10.50x9.13

*Subject to a measurement error of +/- 0.06 inches

PROCEDURE

The transmitter and synthesizer PC boards of the AN/ARC-164 UHF Radio were selected for study because of their representativeness of the types of PC boards typically encountered in maintenance tasks. The component (piece-part) side of the transmitter board (Figure 1) and the pin (solder run) side of the synthesizer board (Figure 2) were used in this study.

Line drawings (paper and pencil) were generated for each of the two PC boards. The drawings contained all of the detail of the actual PC boards. Graphic line drawings of the two boards were then digitized manually using the Digi-Pad 5 graphics digitizer for graphic display on the Megatek 7210 high resolution monitor. The result was a graphic display of the component side of the transmitter PC board and a graphic display of the pin side of the synthesizer PC board.

Forty components on the transmitter board and 20 pins on the synthesizer board were selected as test points for use in the locator task. The 40 components on the transmitter board were divided into 10 groups with each group composed of four similar components matched on size, shape, and proximity to key features (i.e., each of the four components making up a group were all the same size, shape, and type of component and were all located in the same general area of the board). The 20 pins on the synthesizer board were divided into five groups with each group composed of four pins matched on location. Each of the four components/pins within each group were then assigned to different resolution levels. The matching was done in order to reduce the variability between the test points to-be-located in the different resolution levels.

A software program written in CAMIL (Computer Assisted/Managed Instructional Language) was developed for presentation of text and graphics to the students. The software presented instructional text to the students, displayed the graphic line drawings, displayed a flashing arrow at the test point to-be-located by the student, and recorded student performance data gathered during the experiment. A second software program, written in

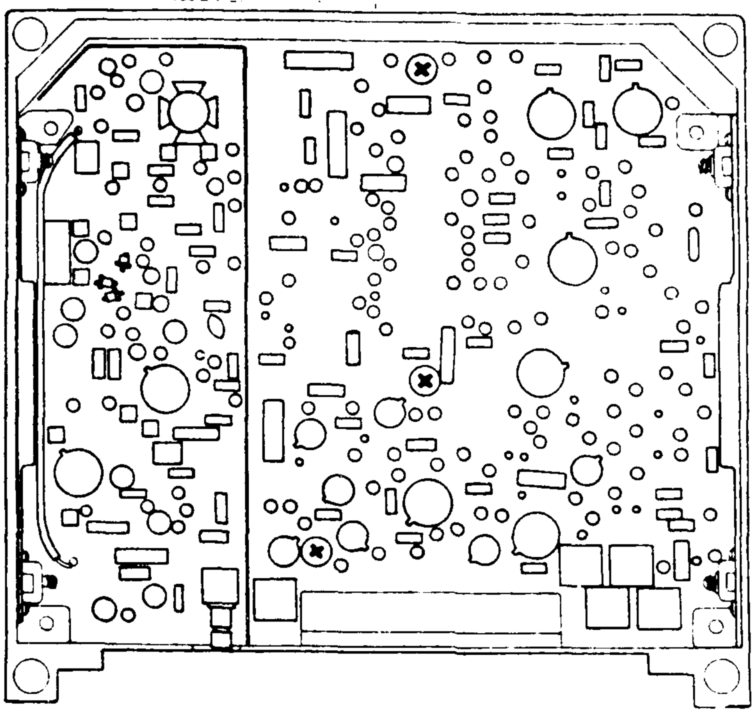

Figure 1. Transmitter PC Board of the AN/ARC-164 UHF Radio (component side).

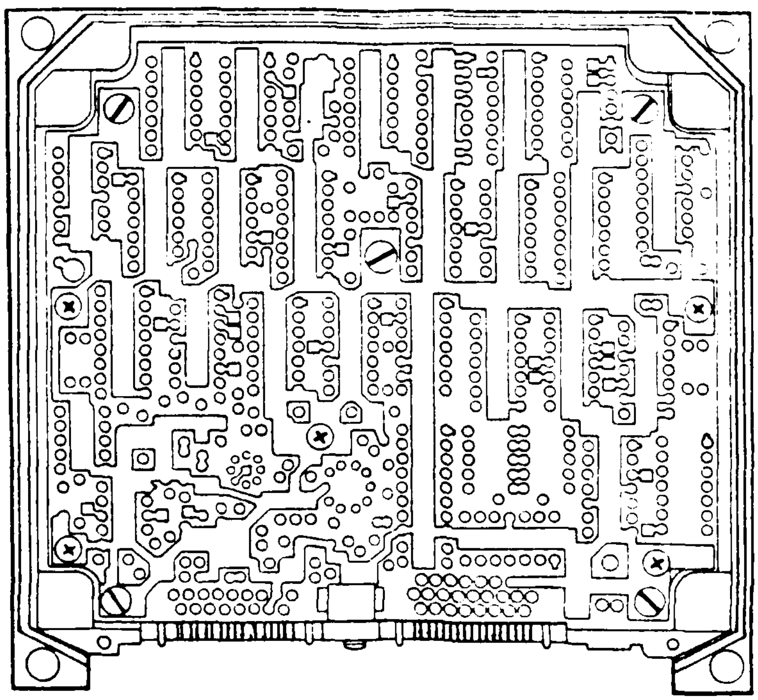

Figure 2. Synthesizer PC Board of the AN/ARC-164 UHF Radio (pin side).

RTRAN, was developed in order to simulate the three display screen sizes hrough electronic masking of a larger display screen) and the four levels of solution.

The four resolution levels were simulated via a software control chnique which involved the use of a coordinate checking and validation ocess. Through this process, specific pixels (dots) were selectively turned (stimulated) or turned off. In the 280 dots per inch condition, all pixels ich composed the line drawing were stimulated; in the 140 dots per inch ndition, one-half of the pixels were stimulated (i.e., every other pixel was rned on); in the 70 dots per inch condition, one-fourth of the pixels were timulated (i.e., 4 pixels were turned off between each stimulated pixel); d in the 35 dots per inch condition, one-eighth of the pixels were timulated (i.e., 8 pixels were turned off between each stimulated pixel). e stimulated/unstimulated pixel array for each resolution level is depicted Figure 3.

Resolution (dots per inch)	Pixels
280	●●●●●●●●●●●●●●●●●●●●●●●●●●●●
140	●o●o●o●o●o●o●o●o●o●o●o●o●o●o
70	●oooo●oooo●oooo●oooo●oooo●oo
35	●oooooooo●oooooooo●oooooooo●

o = Pixel turned off
● = Pixel turned on

Figure 3. Array of Stimulated Pixels By Resolution Level

The 36 students were randomly assigned a student number which orresponded to one of the three display screen sizes. On this basis, 12 tudents were assigned to the 5"x5" screen size condition, 12 students to the "x9" screen size condition, and 12 students to the 12"x12" screen size ondition. Each student was tested individually.

Students were seated approximately 28" from the display screen with no estrictions placed on posture. Each student received general instructions erbally from the experimenter (see Appendix B). Detailed instructions were hen presented on the display screen (see Appendix C). Prior to the actual ocator task trials, each student performed practice trials to a criterion of hree consecutive correctly identified test points. The practice trials used est points which were different than those used in the actual data collection hase and were administered at the resolution level in which the student would egin the actual trials. Thirty-four of the students achieved the criterion

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c. Alternative display media - In the future, electronic JPAs may be expected to be used in field applications (outdoors). Electronic delivery media may make use of different display technologies (e.g., light emitting diodes (LED), electroluminescent panels, plasma panels, liquid crystal, etc.). These media may be better suited for displaying technical information under certain environmental conditions. Also, critical legibility factors should be examined across types of display media to determine the impact on task performance in various environments.

d. JPA devices for training - The potential application of JPA devices to serve a training function (in addition to the aiding function) has been largely untapped. The utility of JPA devices to meet training needs should be determined through systematic investigation.

SECTION V

CONCLUSIONS

The intent of this research was to provide design guidance in support of automated JPA development. Although the research was tailored specifically to JPA design issues related to maintenance functions, the results may apply to other situations in which CRT-based graphics are used. Based upon the findings, the following conclusions are drawn:

1. The 5"x5" display should not be used for graphics with high information density and low discriminability among elements within the graphic. This size should suffice, however, for displays with high discriminability among the elements.

2. Since the 9"x9" and 12"x12" display sizes resulted in statistically equal response accuracies for both the pin side and component side graphics, either size can be used to produce best overall accuracy. Final size selection should be based on other factors (e.g., cost, portability, device size, etc.).

3. Display size had no significant impact on the amount of time required to perform the locator task.

4. Level of resolution had no practical impact on either response accuracy or response time. Design decisions pertaining to the resolution required should, therefore, be based on factors other than accuracy rates and response times (e.g., monitor requirements).

5. Further research is warranted in order to identify optimum visual display parameters for electronic JPAs. Suggested research areas include:

a. Level of detail - When portability and size are critical design issues, smaller displays may be required, yet the data suggest that the 5"x5" display may hinder response accuracy for graphic displays with high information density and low discriminability. Information density can be reduced and discriminability enhanced by varying the amount of detail in the graphic line drawings (i.e., by eliminating non-critical segments of the graphic display). The impact of varying the amount of detail is unknown.

b. Effect on overall maintenance task performance - The study focused on one small step of the entire maintenance process: locating PC board test points. Additional research should focus on tasks more representative of the domain in which automated JPAs will be used: fault isolation, remove and replace, disassembly/assembly, etc. The results of such analyses would provide stronger evidence of the impact of critical legibility variables on overall maintenance task performance when electronic display media are used.

errors are infrequent, emphasis is placed on speed, and each task is completed in a matter of seconds. In this case, a one second difference in search and retrieval time would represent a significant proportion of total task time.

An extra one second in search and retrieval time when JPAs are used to assist in maintenance task performance does not appear to have the same implications as those described by Tullis (1983). Maintaining complex equipment, unlike the tasks in a highly proceduralized production setting, is typically not highly structured, repetitive, or proceduralized, even when JPAs are used. The primary emphasis in maintenance is on accuracy, that is, returning the equipment to a fully operational condition. Often, the entire maintenance task requires several hours to complete.

When performing maintenance tasks, technicians must search for and retrieve technical information (from either paper media such as technical manuals or paper JPAs, microfilm/microfiche, or electronic display media) in order to make the repair. Typically, the time required to locate the critical information is quite short. (In the present study, the overall mean response time was 5.76 seconds for the component side and 6.09 seconds for the pin side). The bulk of maintenance task time is usually devoted to applying the "retrieved" information to the piece of equipment under repair and to actually making the repair. In other words, the information needed (e.g., identifying the test points to be probed) can be obtained rapidly, but implementing that information (actually probing the test points and determining tolerance levels) and then making the repair (removing the faulty module/component and replacing it) account for the majority of the maintenance task time. Thus, one extra second of search and retrieval time represents a very small proportion of total task time.

When examined in the broader context of an overall maintenance task which may require several hours to complete, the small time differences which were evident across resolution levels are put into perspective. Even when a large number of test points must be identified, the cumulative effect of such time differences is still relatively small. Therefore, it appears that the impact of a one second time reduction in locator task performance is negligable, despite the statistically significant differences.

Resolution

Although response accuracy on the pin side PC board graphic improved slightly or remained steady as resolution increased, none of the differences were statistically significant. Similarly, response accuracy between resolution levels on the component side PC board failed to reach statistical significance. In other words, for both PC boards examined, response accuracy in the lowest resolution level (35 dots per inch) was not significantly different than response accuracy in the highest resolution level (280 dots per inch). This finding is in contrast to both Gould (1968), in which 50 dots per inch was identified as the minimum resolution for graphics, and Stahin (1980), who suggests that 70 dots per inch should be the minimum resolution. The data suggest that for tasks such as locating test points on PC boards, level of resolution of the graphic display has little impact on response accuracy.

RESPONSE TIME

Screen Size

The lack of significant response time differences between screen size conditions for both PC boards suggests that screen size neither helped nor hindered locator task response time. In both cases, the 9"x9" screen resulted in the longest response times, however, the times were statistically equal to those in both the 5"x5" and 12"x12" screen size conditions. Thus, the results suggest that display screen size is not critical to the amount of time needed to locate test points.

Resolution

The resolution main effect for the component side graphic demonstrated that student response times varied significantly across resolution levels; this was not true for the pin side graphic where response times were equal for all resolution levels. Despite the statistically significant differences between some response time means, the differences appear to have little practical significance for maintenance JPAs. An examination of the data shows that the greatest difference between the response time means was .98 seconds for the component side (6.21 seconds minus 5.23 seconds; see Table D-5, Appendix D). In other words, students required less than one extra second (on the average) to locate components in the 280 dots per inch condition than in the 140 dots per inch condition.

Tullis (1983) points out that an extra one second in search and retrieval time on each CRT frame of information accessed, translated to an extra 55 person-years needed for extracting such information (based on a company-wide yearly access rate of 344 million CRT frames of information). Such dramatic results, however, would likely be applicable primarily in settings with highly structured, repetitive jobs where tasks are highly proceduralized and where most of the total task time is devoted to searching a display screen for information. In this type of setting, tasks are relatively easy to perform,

SECTION IV

DISCUSSION

The two dependent measures used in this study, response accuracy and response time, are discussed below in terms of the two independent variables examined, screen size and resolution.

RESPONSE ACCURACY

Screen Size

Screen size had an affect on response accuracy only when discriminability between test points was low. According to the data, graphic displays with large numbers of highly similar test points located in proximity to one another, such as in the case of the pin side PC board graphic, warrant larger display screens. This is evidenced by the significant response accuracy difference between the 5"x5" and 12"x12" screen sizes on the pin side graphic, where accuracy was almost eight percentage points higher in the 12"x12" condition. When discriminability between test points is high, such as with the component side PC board graphic, accuracy was not affected by screen size. Based on these findings, it appears that screen size is critical to accuracy only when the individual elements of the display (i.e., test points) are highly repetitious and densely packed. These findings may be explained when one examines the information density of the component and pin side graphic displays.

The component side graphic contains a relatively small number of test points dispersed throughout the PC board. The test points vary widely in size and shape, and because of this diversity, several unique landmarks (cues) are prevalent. These landmarks may serve as reference points which aid the student in "narrowing the search" down to a small group of test points from which final identification is made. Because of the variety of shapes and sizes, there is little competition from surrounding components. As a result, the ability to discriminate between components is relatively easy. Consequently, locator task performance is stable across conditions and accuracy scores fluctuate only slightly.

In contrast to the component side graphic, the pin side graphic is composed of a large number of highly similar, densely packed test points. According to Galitz (1980), high information densities contribute to "competition among screen components for a person's attention" (p. 108). This high level of information density, coupled with a small display screen tends to "squeeze" the elements of the display together, which may have hindered searching behavior. However, as screen size increases, compactness is reduced, the picture is expanded, and because the display is easier to scan, searching for test points is facilitated. Similar explanations have been offered by Jones (1978) for alphanumeric displays.

Component Side PC Board

The lack of a main effect for screen size (means = 5.66 seconds, 5.91 seconds, and 5.70 seconds), ($p > .05$), suggests that response time was not significantly impacted by screen size. However, the analysis did reveal a main effect for resolution, $F(3,99) = 6.91$, $p < .01$, indicating that significant response time differences existed between resolution levels (means = 6.00 seconds, 5.59 seconds, 5.23 seconds, and 6.21 seconds). Duncan's multiple range test identified statistically significant response time differences between the 35 and 140 dots per inch conditions, between the 70 and 280 dots per inch conditions, and between the 140 and 280 dots per inch conditions; ($p < .05$ in all cases). The data show that response time was shortest when the graphic display was presented at the 140 dots per inch resolution level (5.23 seconds) and longest when presented at the 280 dots per inch resolution level (6.21 seconds). No interaction between screen size and resolution was revealed, ($p > .05$). Table D-5 (Appendix D) presents the means and standard deviations for the component side response time data, analyzed by screen size and resolution. Table D-6 (Appendix D) is the summary table for the ANOVA performed on these data.

Pin Side PC Board

No main effects were found for screen size (means = 6.12 seconds, 6.30 seconds, and 5.85 seconds) or for resolution (means = 6.38 seconds, 5.75 seconds, 6.11 seconds, and 6.11 seconds), ($p > .05$) suggesting that neither variable significantly impacted response time. No screen size by resolution interaction was revealed in the analysis, ($p > .05$). The means and standard deviations for the pin side response time data, analyzed by screen size and resolution, are presented in Table D-7 (Appendix D). Table D-8 (Appendix D) is the summary table for the ANOVA performed on these data.

SECTION III

RESULTS

RESPONSE ACCURACY

The number of test points correctly identified by each student for each condition was converted to a percentage correct score and the analyses were performed on these percentages.

Component Side PC Board

The ANOVA revealed no main effect for either screen size (means = 89.59%, 93.75%, and 90.42%) or resolution (means = 91.11%, 93.33%, 89.72%, and 90.83%), ($p > .05$), suggesting that response accuracy is not significantly impacted by either variable. No interaction between screen size and resolution was evident in the analysis, ($p > .05$). The means and standard deviations for the component side response accuracy data, analyzed by screen size and resolution, are presented in Table D-1 (Appendix D). Table D-2 (Appendix D) is the summary table for the ANOVA performed on these data.

Pin Side PC Board

The analysis of the response accuracy data for the pin side PC board revealed a main effect for screen size, $F(2,33) = 5.41$, $p < .01$, indicating that screen size significantly affected accuracy rates (means = 90.83%, 95.00%, and 98.75%). Duncan's multiple range test identified significant response accuracy differences between the 5"x5" (90.83%) and 12"x12" (98.75%) screen size conditions, ($p < .05$). Student locator task performance was significantly more accurate when the stimulus material (i.e., the graphic synthesizer board) was presented on the 12"x12" display screen than when presented on the 5"x5" display screen. No other differences between screen size means reached statistical significance.

No main effect was found for resolution (means = 92.22%, 95.00%, 95.00%, and 97.22%), suggesting that resolution did not have a significant impact on accuracy, nor was a screen size by resolution interaction evident in the analysis, ($p > .05$). Table D-3 (Appendix D) presents the means and standard deviations for the pin side response accuracy data, analyzed by screen size and resolution. Table D-4 (Appendix D) is the summary table for the ANOVA performed on these data.

RESPONSE TIME

The number of seconds taken by each student to locate each test point was recorded for all conditions. These data were then converted to scores which represented each student's average response time for locating test points in each condition. The analyses were performed on these (average) response time data.

variables or the differences between the PC boards. To further clarify the results, subsequent analyses were performed using Duncan's multiple range test (Brunning and Kintz, 1977) for pairwise comparisons among the means of significant effects.

in three or four practice trials, one student required six practice trials, and one student required 10 practice trials.

All 12 students in each group then completed four sets of 15 locator task trials, one set for each level of resolution. Each set of trials consisted of first locating and identifying 10 components on the actual transmitter PC board and then locating and identifying 5 pins on the actual synthesizer PC board, based upon the component/pin identified by the flashing arrow on the graphic display. Thus, each set consisted of 15 trials (10 components and 5 pins) and each student performed a total of 60 different trials across the four levels of resolution. The order of presentation for level of resolution was counterbalanced in order to ensure that the repeated measures were independent and to control for learning effects.

Due to hardware limitations and the amount of detail depicted in the graphic line drawings, the data lists which were used to generate the graphic displays of the PC boards tended to overload the computer's refresh rate. This resulted in slow drawing times of the graphic PC boards (51 seconds for the transmitter board and 103 seconds for the synthesizer board), and a slight flickering of the CRT display. The slow drawing times which occurred each time the display changed from one PC board to the other (i.e., four times for the transmitter board and four times for the synthesizer board) could not be averted and were witnessed by all students. The flickering of the display, however, was reduced substantially by darkening the room and permitting each student to adjust the intensity control on the monitor. A dimly lit table lamp was used at the experimental station so that student and instructor could see the actual PC boards used in the locator task. Despite these alterations, a very slight flicker remained. Student comments related to the flicker were minimal.

PERFORMANCE MEASURES

Response accuracy (correct/incorrect) on the locator task was assessed by the experimenter and manually entered into the computer following each trial. The experimenter was an electrical engineer, knowledgeable in PC board layout and design. Response time (in seconds) was recorded by the computer from the time the test point to-be-located was identified by the flashing arrow until the student said "stop" and the experimenter typed "s" on the keyboard. Response accuracy and response time data were stored by the computer on disk for subsequent analysis.

DESIGN AND ANALYSIS

The experiment employed a 3x4 mixed design with three levels of screen size as the between-subjects factor and four levels of resolution as the repeated or within-subjects factor. Separate analyses of variance (ANOVAs) were performed for each of the two PC boards and for the two dependent variables, response accuracy and response time. The four separate ANOVAs were performed because this method is the most efficacious means for data interpretation and does not confound the results of the two dependent

Wald, G., "Blue-Blindness in the Normal Fovea." _Journal of the Optical Society of America_, Vol. 57, No. 1, pp. 1298-1303, 1967.

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APPENDIX A

SUMMARY OF PAST RESEARCH

TABLE A-1. Visual Display Parameters for Electronic Display Media - A Summary of Past Research

PARAMETER	RECOMMENDATIONS	REFERENCES
Case of Letters	Upper and lower case are recommended for continuous text. Descenders on lower case letters should extend below the line. (Note: most research has been based on hardcopy text).	Vartebedian, 1971b; Cakir et al; 1980; Craig, 1980; Campbell et al., 1981.
Chromaticity	The blue end of the spectrum should be avoided for monochromatic displays. The center of the spectrum is easiest to see under normal viewing conditions but the red end of the spectrum is easiest to see under high ambient illumination.	Rizy, 1967; Wald, 1967; Gould, 1969; Snowberg, 1971; Alexander et al., 1974; Ellis et al., 1975; Tyte et al., 1975; Krebs et al., 1978; Sherr, 1979; Shurtleff, 1980.
Coding	Numerical, color, blink, brightness, underline, or reverse video codes can be used. Numerical coding may be best for identification tasks.	Christner & Ray, 1961; Hitt, 1961; Semple, 1971; Christ, 1975; Christ, 1977; Krebs et al., 1978; Sherr, 1979; Cakir et al., 1980; Tullis, 1981.
Contrast Ratio	A minimum of 10:1 is needed with higher levels preferred when ambient illumination (background lighting) is high. Inclusion of a contrast control is preferred.	Crook et al., 1954; Howell & Kraft, 1959; Carel, 1965; Snyder & Maddox, 1978; Sherr, 1979; Craig, 1980; Shurtleff, 1980.
Direction of Contrast	Either light-on-dark or dark-on-light is acceptable.	McLean, 1965.
Dot Matrix Size (per character)	A 5x7 matrix is the minimum acceptable. A 7x9 or larger matrix is preferred, particularly where display quality is impaired.	Shurtleff, 1970a and b; Vartebedian, 1971; Scanlan and Carel, 1976.
Dot Shape and Spacing	Round dots should be used with a minimum active area of 30 percent.	Vartebedian, 1971a; Vandervolk et al., 1975; Stein, 1976.

PARAMETER	RECOMMENDATIONS	REFERENCES
Font of Characters	Most popular fonts (e.g., Lincoln/MITRE, NAMEL, Leroy) are acceptable. Serifs, slanted letters, and variable stroke widths should be avoided. (Note: Most recommendations for CRT fonts have been based on extrapolation from non-CRT research).	Brown, 1953; Ketchell & Jenny, 1968; Shurtleff, 1970; Semple et al., 1971; Vartebedian, 1971; Vandervolk et al., 1975; Riley & Barbato, 1978; Shurtleff, 1980.
Flicker	The persistance of the particular phosphor used in the display device should be taken into account when determining critical fusion frequency (CFF). Generally speaking, a refresh rate of 50-60 Hz is acceptable.	Gould, 1968; Sherr, 1979; Cakir et al., 1980.
Glare and Relections	Matte screens are recommended. Filters may be needed under poor viewing conditions.	Hultgreen & Knave, 1974; Cakir et al., 1980.
Horizontal Symbol Spacing	Space between symbols should be 25 percent of symbol height. Under optimum viewing conditions, spacing as close as 10 to 15 percent of symbol height can be used. Off-axis viewing angles which exceed 45 degrees require 25 to 50 percent spacing.	Crook et al., 1954a and b; Shurtleff & Alexander, 1972; Shurtleff, 1980; Kolers et al., 1981; Sherr, 1982.
Luminance	Minimum requirement is 34 to 50 nits (candelas per square meter). Higher values are preferred, particularly when ambient illumination (background lighting) is high. An adjustment control is preferred.	Faulkner & Murphy, 1973; Sherr, 1979; Cakir et al., 1980; Shurtleff, 1980; Campbell et al., 1981.
Resolution	The higher the resolution, the better. Maximum usable resolution occurs when display element size subtends one minute of arc. Fifty lines per inch is the minimum for graphics.	Gould, 1968; Biberman, 1973; Sherr, 1979; Craig, 1980.
Scrolling	If used, scrolling should be smooth.	Kolers et al., 1981.
Stroke vs. Dot Generated Symbols	Either stroke or dot generated symbols are acceptable.	Shurtleff, 1974; O'Donnel & Gomer, 1976; Schnessler, 1976; Vandervolk, 1976; Sherr, 1979.

PARAMETER	RECOMMENDATIONS	REFERENCES
Stroke Width	Stroke width should be 12 to 20 percent of symbol height with the wider end of the range generally better.	Crook et al., 1954a and b; Sherr, 1979; Cakir et al., 1980, Craig, 1980; Shurtleff, 1980.
Symbol Height	Symbol height should be in the range of 16 to 22 minutes of arc.	Woodson & Conover, 1964; Ketchel & Jenny, 1968; Sherr, 1979; Cakir et al., 1980; Shurtleff, 1980; Campbell et al., 1981; Sherr, 1982.
Symbol Resolution	Ten to 12 scan lines per symbol height are needed for CRT displays.	Shurtleff, 1966; Gould, 1968; Cakir et al., 1980; Craig, 1980; Shurtleff, 1980; Campbell et al., 1981.
Symbol Width-to-Height Ratio	Symbol width should be in the range of 70 to 80 percent of symbol height.	Semple et al., 1971; Buckler, 1977; Sherr, 1979; Cakir et al., 1980, Shurtleff, 1980.
Vertical Line Spacing	Space between rows of text should be equal to 50 percent of symbol height.	Streeter et al., 1978; Cakir et al., 1980; Craig, 1980; Kolers, 1981.
Viewing Angle	Viewing angle should not exceed 19 degrees. This should not present a problem as the user should be able to move the display or change viewing angle.	Seibert et al., 1959; Shurtleff, 1980.
Visual Fatigue	Further research is needed on the effects of using electronic information delivery on visual fatigue of the user. Fatigue may be partially due to work station layout.	Hultgreen & Knave, 1974; Dainoff et al., 1981; Matula, 1981; Mourant et al., 1981.

APPENDIX B

VERBAL INSTRUCTIONS TO STUDENTS

Good morning (afternoon). My name is Erich Pearson and I will be the instructor for this exercise. You have been selected to participate in a study that will help the Air Force determine the best way to show maintenance information on a computer screen. The specific instructions will be presented to you on the computer screen, so I will not go over them here. The entire exercise should take about an hour and a half. Before we get started, you will have a few practice trials so that if you are confused and have any questions, you can ask them during practice. So, if you're ready, we'll begin.

APPENDIX C

STUDENT INSTRUCTIONS PRESENTED ON CRT

FRAME ONE:

INSTRUCTIONS

You are part of a study to find the best way to show maintenance information on a computer screen. In front of you is:

1. A computer screen
2. A section from a radio
3. A pencil to use as a pointer

The person next to you is the instructor running the study. Tell him when you have finished reading.

FRAME TWO:

The computer screen will show you a drawing of a section of a radio. The shapes on the drawing are the same as the shapes of the parts on the radio section. The instructor will show you how to hold the section of the radio so that the parts on the drawing will match those on the radio. He will then show you how to find one of the parts. Tell him when you have finished reading.

FRAME THREE:

You will be allowed to practice some before the scoring starts. When you tell the instructor that you are ready, one of the parts on the drawing will have an arrow drawn to it. You must:

1. LOCATE THE PART ON THE RADIO
2. POINT TO THE PART WITH THE POINTER AND SAY 'STOP'
3. KEEP THE POINTER ON THE PART UNTIL THE INSTRUCTOR TELLS YOU THAT YOU MAY MOVE IT

FRAME FOUR:

You will be scored on how fast you find the parts and on whether you find the right parts. Work fast but be sure you find the right part. If you have any questions, please ask the instructor now.

FRAME FIVE: (Presented after the first ten trials in each set)

The instructor will now give you another section of the radio. The new section has one side removed to show a board covered with little silver connections. The instructor will show you how to hold it so that it matches the drawing on the screen and how to find one of the connections. You are to point to the connections on the radio section just as you did the radio parts. Remember, you are being scored on speed and accuracy. If you have any questions, please ask the instructor now. Otherwise, ask your instructor for the new radio board.

APPENDIX D

MEANS, STANDARD DEVIATIONS AND SUMMARY TABLES FOR RESPONSE ACCURACY AND RESPONSE TIME DATA

TABLE D-1
MEANS AND STANDARD DEVIATIONS FOR RESPONSE ACCURACY DATA
ANALYZED BY SCREEN SIZE AND RESOLUTION
(COMPONENT SIDE)

SCREEN SIZE		RESOLUTION				
		35	70	140	280	Row Means[a] (n=12)
5x5	M	89.17	92.50	86.67	90.00	89.59
	SD	9.96	6.22	7.78	7.39	7.98
9x9	M	94.17	96.67	91.67	92.50	93.75
	SD	7.93	4.92	7.18	11.38	8.15
12x12	M	90.00	90.83	90.83	90.00	90.42
	SD	8.53	5.15	7.93	12.06	8.49
Column Means[b] (N=36)	M	91.11	93.33	89.72	90.83	
	SD	8.87	5.86	7.74	10.25	

Note. The values represent mean percent correct scores.

[a]Average of the 4 resolution means.

[b]Average of the 3 screen size means.

TABLE D-2
ANALYSIS OF VARIANCE SUMMARY TABLE FOR RESPONSE ACCURACY DATA
(COMPONENT SIDE)

SOURCE	df	SS	MS	F
Between Subjects	35	4625.00		
Screen Size	2	466.67	233.33	1.85
Error	33	4158.33	126.01	
Within Subjects	108	5350.00		
Resolution	3	247.22	82.41	1.65
Screen Size x Resolution	6	144.44	24.07	0.48
Error	99	4958.33	50.08	

TABLE D-3
MEANS AND STANDARD DEVIATIONS FOR RESPONSE ACCURACY DATA
ANALYZED BY SCREEN SIZE AND RESOLUTION
(PIN SIDE)

SCREEN SIZE		RESOLUTION				
		35	70	140	280	Row Means[a] (n=12)
5x5	M	90.00	88.33	90.00	95.00	90.83
	SD	23.35	10.30	15.95	9.05	15.41
9x9	M	90.00	96.67	95.00	98.33	95.00
	SD	13.48	7.79	9.05	5.77	9.68
12x12	M	96.67	100.00	100.00	98.33	98.75
	SD	7.79	0.00	0.00	5.77	4.89
Column Means[b]	M	92.22	95.00	95.00	97.22	
(N=36)	SD	16.05	8.78	11.08	7.01	

Note. The values represent mean percent correct scores.

[a]Average of the 4 resolution means.

[b]Average of the 3 screen size means.

TABLE D-4
ANALYSIS OF VARIANCE SUMMARY TABLE FOR RESPONSE ACCURACY DATA
(PIN SIDE)

SOURCE	df	SS	MS	F
Between Subjects	35	6097.22		
Screen Size	2	1505.56	752.78	5.41*
Error	33	4591.67	139.14	
Within Subjects	108	12,100.00		
Resolution	3	452.78	150.93	1.33
Screen Size x Resolution	6	405.56	67.59	0.60
Error	99	11,241.67	113.55	

*p < .01

TABLE D-5
MEANS AND STANDARD DEVIATIONS FOR RESPONSE TIME DATA
ANALYZED BY SCREEN SIZE AND RESOLUTION
(COMPONENT SIDE)

SCREEN SIZE		RESOLUTION				
		35	70	140	280	Row Means[a] (n=12)
5x5	M	5.95	5.43	5.28	5.99	5.66
	SD	1.46	1.35	0.95	1.58	1.35
9x9	M	6.31	5.37	5.48	6.47	5.91
	SD	2.59	1.30	1.26	1.85	1.84
12x12	M	5.73	5.97	4.93	6.17	5.70
	SD	1.32	1.39	0.95	1.96	1.48
Column Means[b] (N=36)	M	6.00	5.59	5.23	6.21	
	SD	1.84	1.33	1.06	1.77	

Note. The values represent mean response times in seconds.

[a]Average of the 4 resolution means.

[b]Average of the 3 screen size means.

TABLE D-6
ANALYSIS OF VARIANCE SUMMARY TABLE FOR RESPONSE TIME DATA
(COMPONENT SIDE)

SOURCE	df	SS	MS	F
Between Subjects	35	225.36		
Screen Size	2	1.61	0.80	0.19
Error	33	223.75	6.78	
Within Subjects	108	124.08		
Resolution	3	20.41	6.80	6.91*
Screen Size x Resolution	6	6.21	1.03	1.05
Error	99	97.46	0.98	

*$p < .01$

TABLE D-7
MEANS AND STANDARD DEVIATIONS FOR RESPONSE TIME DATA
ANALYZED BY SCREEN SIZE AND RESOLUTION
(PIN SIDE)

SCREEN SIZE		RESOLUTION				
		35	70	140	280	Row Means[a] (n=12)
5x5	M	6.90	5.60	6.12	5.85	6.12
	SD	2.26	1.43	1.83	1.91	1.89
9x9	M	6.35	6.32	6.18	6.35	6.30
	SD	1.79	2.65	2.76	1.40	2.15
12x12	M	5.90	5.33	6.03	6.13	5.85
	SD	1.47	1.37	1.53	1.63	1.49
Column Means[b] (N=36)	M	6.38	5.75	6.11	6.11	
	SD	1.86	1.90	2.04	1.63	

Note. The values represent mean response times in seconds.

[a] Average of the 4 resolution means.

[b] Average of the 3 screen size means.

TABLE D-8
ANALYSIS OF VARIANCE SUMMARY TABLE FOR RESPONSE TIME DATA
(PIN SIDE)

SOURCE	df	SS	MS	F
Between Subjects	35	288.90		
Screen Size	2	4.92	2.46	0.29
Error	33	283.99	8.61	
Within Subjects	108	167.96		
Resolution	3	7.29	2.43	1.59
Screen Size x Resolution	6	8.96	1.49	0.97
Error	99	151.71	1.53	

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